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PLATE VII

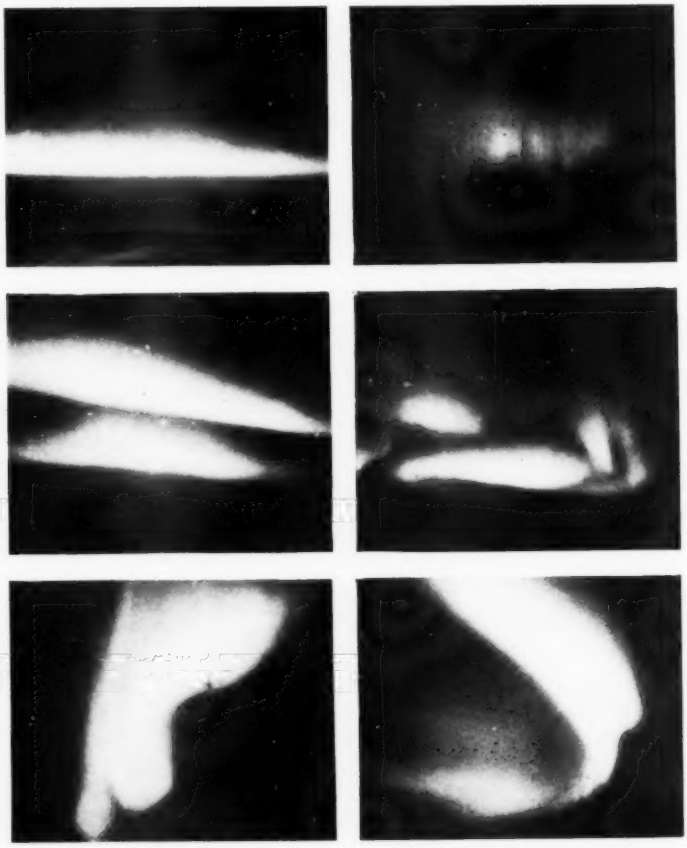

Fig. 1.—Some typical forms of aurora. Photographed at Chesterfield in 1932-33.

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THE POLAR AURORA

By B. W. CURRIE

(With Plate VII)

INTRODUCTION

THE polar aurora is a self-luminous phenomenon of the upper atmosphere, and, as the name suggests, is seen most frequently in high latitudes. However, auroral displays have been observed to at least latitude 14° in both the Northern and Southern Hemispheres. Although a detailed study has never been made of the simultaneous occurrence of auroras in the two hemispheres, it is practically certain that widespread displays in one are accompanied by similar displays in the other.

The great variety of distinct forms, the rapid changes of position and brightness, the vivid colours and the sudden and irregular appearances at lower latitudes have impressed both ancient and modern peoples. Auroras are mentioned in Aristotle's *Meteorologica;* and flame-like displays in the sky are described in Seneca's *Naturales Questiones.* In the latter, reference is made to one that caused the soldiers of Tiberius to believe that Ostia was on fire, an illusion, curiously enough, that was repeated as recently as January 25, 1938, in parts of southeastern Europe, where fire engines raced toward red auroral glows on the horizons. Early historical records generally show that the appearance of aurora at lower latitudes was considered a warning of an impending disaster. Even to-day, many people, living at lower latitudes, believe that auroras precede great storms, or unseasonal frosts, or very cold weather.

Evidence exists that the Chinese noted before the Christian era that auroras were frequent when sunspots were visible. Changes of the compass direction during auroral displays were observed as early

as 1716 by Halley. When the first telegraph lines were constructed a little more than a century ago, the discovery was made that auroras were often accompanied by varying electric currents in the earth's surface—currents that interfered with the transmission of messages and led to the telegrapher's description of the interference as an "aurora on the line". The fact that erratic fading of radio messages sometimes occurs during transmission close to or through the zones of maximum auroral occurrence became evident during the past twenty years. To-day it is generally accepted that auroras are an indication that charged particles from the sun are reaching the earth's atmosphere, and that these currents of charged particles together with the ionization produced by them in the upper atmosphere are responsible for the magnetic, earth-current and radio disturbances. Although auroral displays are probably a secondary manifestation of the ionic conditions responsible for these disturbances, auroral observations have given and will continue to give much information on the variations with time and place of such disturbances. In addition, suitable auroral observations yield information concerning the constitution and physical state of the upper atmosphere.

Observations

Auroral observations fall into four groups, namely, visual, single-station photographic, double-station photographic and spectrographic. Visual observations are an effective means of getting the times of occurrence, the spatial distributions of aurora and the characteristic changes in form and activity at various places. Obviously, their usefulness is greatly enhanced when they are made regularly throughout the night, and at a network of stations which are within 200 to 300 miles of each other. Single-station photographs are particularly useful for recording complex details of a display that is changing slowly enough to permit time-exposures of several seconds for each picture. The star backgrounds fix the altitudes and the azimuths of significant features of the display. The simultaneous photographing of the same part of a display from two stations at a known distance apart is designed to locate the exact position in space of the auroral luminosity. The very considerable labours required in determining these positions from the photographs limit the number of such observations. Spectrographic observations indicate the constitution of the atmosphere and the average excitation conditions at auroral levels. Exposures of several hours are required to photograph the weaker spectral emissions

even with spectrographs designed for a large light-gathering power and small dispersion. The special type of spectrograph required for this work has effectively limited observations of this kind.

The value of visual observations depends greatly on the persistence and care exercised by the observer. A common fault is not to observe regularly and at the same times on successive nights. Another is to omit all reference to the observations when auroras were not seen, although some of the non-appearances must have been due to obscuring cloud or moonlight as well as to lack of aurora. The direction and elevation of the base of the highest part of the display in the observer's sky are often omitted, although these are essential to locate the place where the display was overhead when the geographical incidences of auroras are compared with the records of magnetic, earth-current and ionosphere stations. The need for carefuly measuring the lower altitudes is evident when it is realized that a display with its base at an elevation of 45° or more is overhead at a point within 60 miles of the observer, whereas one with an elevation of 5° or less is overhead more than 500 miles from the observer. Estimates of relative brightness are often included in visual reports, but the value of doing so is doubtful since they have proven useless for correlation studies. Apparently the estimated values vary greatly with the conditioning of the observer's eyes to darkness at the time of an observation and with his past experience at observing auroras with a large range of luminosities.

Much visual material has accumulated for the northern part of this continent, but very little is readily available for statistical investigations. In most cases the original records must be consulted and the desired information tabulated before a beginning can be made on an investigation. This situation is not only handicapping investigations on the geographical incidence of aurora, but is also preventing a clear insight into how current observations should be modified so as to further auroral studies.

Single-station photographs are particularly useful for fixing the zenithal locations and the orientations relative to the earth's surface of quiet, homogeneous types of aurora. This is done by determining the altitudes and azimuths of a number of points along the base of the aurora from the star background and then projecting each point vertically onto the earth by assuming a constant height of 100 to 110 km. for the base. The advantages of this method were first demonstrated by Sverdrup (1). Later it was used by Currie and Jones (2)

to determine the directional characteristics of aurora in Canada from the single-station photographs taken at Cape Hopes Advance, Chesterfield and Coppermine during the International Polar-Year, 1932-33. Recently Harang (3) has recommended some improvements to the procedures. Essentially the same method can be applied to a sketch that shows the lower edge of the aurora on a star map. In either case, the exact time must be noted so that the positions of the stars relative to the station can be determined.

The successful application of double-station photography to the location of aurora in the atmosphere is largely due to the efforts of Störmer, Vegard, Krogness and Harang. They developed many ingenious graphical aids for measuring parallactic displacements of corresponding points on a pair of photographs and determining the directions and distances of these points from the principal photographic station. Hewson (4) has given a brief summary of these methods in an excellent survey of the facts and theories of aurora. In spite of these aids, the required measurements and computations are time-consuming; and investigations of this type should not be attempted before adequate provision has been made for measuring the plates.

The most extensive application of double-station photographic methods has been in southern Norway where, according to Störmer (5), about 32,000 usable auroral photographs had been taken and 12,330 heights had been measured in the period 1911-44. The first height measurements in North America were made in 1931 by McLennan, Wynne-Edwards and Ireton (6). Fuller and Bramhall (7) carried out a series of measurements at College, Alaska, from 1930 to 1934. The Canadian groups participating in the International Polar-Year, 1930-33, determined heights at Chesterfield and Saskatoon (8). A large number of parallactic photographs were taken at the same time by the British party at Fort Rae, but no determinations of heights from them have been published.

Spectrographic observations of aurora have been made almost exclusively in Norway, and by Vegard, Störmer and their collaborators. A large number of their publications on this subject are listed in "Terrestrial Magnetism" (J. A. Fleming, Editor) and "Geomagnetism" by Chapman and Bartels. Some 700 spectrograms were taken at Chesterfield during 1932-33 with a spectrograph having a very high light-gathering power and consequently a small dispersion; and considerable information (9) concerning the relative occurrence of

the stronger auroral radiations was obtained. A great need exists for further spectral studies with spectrographs of larger dispersion. The improvements in optical materials, and their design and surfacing with non-reflecting films during the recent war should make this possible.

Types of Aurora

Several distinctive types of aurora are readily recognized, although various modifications of some or all of the types may occur during the course of a display. The main classification is according to activity,—quiet or active. Quiet types changes their positions and brightness rather slowly, and usually predominate during the earlier part of a display. Active types change their positions rapidly, are usually accompanied by rapid pulsations or waves of light running either parallel to the horizon or upward to the zenith and by changes of colour from the normal yellowish-green to vivid shades of pink, red and even blue, and often mark the culmination of a display. These two types are then subdivided according to form into glows, arcs, bands, rays, draperies and coronas. Glows, and homogeneous arcs and bands are usually associated with the quiet type; rays, arcs and bands showing a ray structure, and coronas with the active type. A number of typical forms, that were photographed at Chesterfield in 1932-33, are shown in figure 1. Starting at the top and going from left to right they are as follows—a homogeneous arc, a ray arc, a double homogeneous arc, a ray band, a drapery, and a band in the shape of a horseshoe. A picture of a corona is not included, but it is easily recognized by the visual illusion that the rays in the corona meet, (if extended upward), at a point in the centre. This point for most places in Canada is south of the observer's zenith.

It is generally known that the frequencies of these types vary with location, but no one has attempted a systematic study of these variations with latitude. Distant from the zones of maximum occurrence, glows and homogeneous arcs are the predominating types, draperies and coronas only occurring during bright displays. Close to the zones, all the usual forms are seen during the course of most displays. Other significant differences in the general features of displays, such as the definition, the sequence of appearance and disappearance of the various forms during a display, the coloration, etc., also vary apparently with latitude. Some of these differences between displays during 1932-33 at Fort Rae on Great Slave lake and at Meanook about 500 miles due south are mentioned by Vestine (10).

Undoubtedly equally marked differences between other places could be found by a careful examination of the visual observations.

Geographical Distribution

The first comprehensive study of the average number of days per year with aurora in relation to geographical position was made by Fritz (11). This was for the Northern Hemisphere, and was based on observations for the years from 1700 to 1872. His map of isochasms of equal auroral frequency was the standard reference for the geographical distributions of auroras until 1944, when Vestine (12) constructed a map for the Northern Hemisphere by combining Fritz's auroral frequencies with frequencies deduced from the more extensive observations made at higher latitudes since 1872. Figure 2 is based on Vestine's map for the annual frequency of days with visible auroral

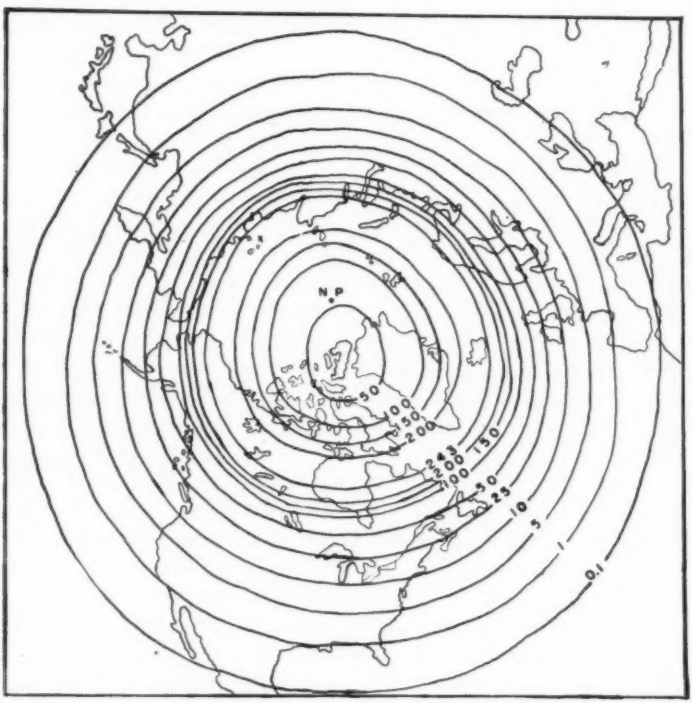

Fig. 2.—Zones of visible occurrence of aurora.

displays in the Northern Hemisphere. A similar type of map has been constructed by Vestine and Synder (13) for the Southern Hemisphere.

From figure 2 it is evident that the zone of maximum visible occurrence for the Northern Hemisphere runs along the northern coasts of Asia and Europe, crosses the Atlantic Ocean to the south of Iceland and Greenland and traverses Canada by way of northern Quebec, Hudson Bay, the southern part of the Northwest Territories and the Yukon. Along this zone aurora is visible at some time during almost every clear night. Both inside and outside of the zone the number of days with aurora decreases fairly rapidly with distance.

One feature of this map, (as well as Fritz's), is worth noting. The frequency lines are based on the number of times that aurora was seen at various places, and do not take into account the fact that aurora to the south of the maximum zone is usually seen in the observer's northern sky and is overhead at a point some hundreds of miles north of him. The same is true of observations to the north of the maximum zone where the aurora is usually in the observer's southern sky. Isolines of this type are useful for indicating how often aurora may be seen at a particular place, but fail to show the geographical distribution of overhead aurora, which is needed for correlations of magnetic, earth-current and ionosphere conditions with aurora.

A noteworthy feature of the map is the tendency for the isolines to be distributed symmetrically about the north geomagnetic pole and not about either the north geographic pole or the north magnetic dip-pole. The geomagnetic poles are the points on the earth's surface through which would pass the axis of a small, powerful magnet which, if placed at the earth's centre, would have at the surface a magnetic field approximating closely to the observed field. The point for the Northern Hemisphere is located in northwestern Greenland at about 78.5°N. and 69°W. The observed position of the isolines is taken as a definite indication that the geographical distribution of aurora is determined in part by the earth's magnetic field. It also indicates that studies of the geographical variations of aurora should be simplified by the use of geomagnetic latitude, longitude and time. This reference system differs from the one in common use by having its poles at the geomagnetic instead of the geographic poles.

No serious attempt has been made to determine either the average number of hours or the average total time per year with visible aurora.

Very approximate estimates by the writer, using some of the Canadian observations, indicate that aurora is visible at some time during 60 per cent. of all clear dark hours at places close to the zone of maximum frequency and less than 30 per cent. at distances of 400 or more miles from it. The total time with visible aurora is unquestionably a small fraction of the total possible time, and will require some form of continuous recorder for its measurement.

Variation with Time

There is definite evidence of a long-period variation that is similar to the sunspot cycle, a 27- to 28-day period related to the rotation period of the sun, an annual variation with maxima at the equinoxes and minima at the solstices, and a diurnal variation with a principal maximum that apparently occurs at different local mean times for different places. In the majority of cases these variations have been deduced by using frequencies of appearance, although somewhat similar variations are evident in the brightness and activity of displays. As a result, it is uncertain whether the increases in frequencies of appearance are real or are simply due to the improved possibility of seeing weak displays which would otherwise be missed because of cloudy skies and moonlight.

The general increase in brightness of aurora is evident at sunspot-maximum for all latitudes. Close to and at the zone of maximum frequency the number of days per year with aurora does not change significantly with the sunspot cycle; but at considerable distances a marked increase per year occurs from about a year before to about two years after sunspot-maximum, and a pronounced decrease shortly after sunspot-minimum. This was clearly demonstrated by Clayton (14), using a 55-year record of auroras at Blue Hill Observatory, Massachusetts. There is also some evidence that the northern zone of maximum frequency is displaced southward rather than broadened at sunspot-maximum. If such is the case, places inside the zone should experience a slight decrease of frequency on these occasions.

The tendency of both active and unusually quiet auroral periods to recur at intervals of from 27 to 29 days later has been found at a sufficient number of places to show that it is a fundamental characteristic of aurora. It is generally assumed that sunspots, or other active regions associated with sunspots, crossing the central area of the sun are responsible for this recurrence. This assumption was examined in detail by Clayton (14), using the Blue Hill Observatory

data. He found that a maximum of spots in the central area of the sun preceded the occurrence of aurora by one day, that the greatest area of spots in the central zone of the sun preceded the aurora by from one to four days, and that auroras are frequently brilliant when large spots pass within 20° of the sun's centre. However, Dixon (15) using Lerwick Observatory (Shetland Islands) auroral data for 80 years, has deduced a period of 27.3 days in auroral occurrence. This is more than the aforementioned 27-day recurrence that only continues for a few solar rotations, since his period has persisted for 80 years. Evidently there exists an area on the sun's surface which moves only slightly in longitude and which activates aurora.

The more frequent appearances of aurora during the equinoctial months, September, October, March and April, than during December and January have been well established for places outside the northern maximum zone. However, some observations close to the zone show a midwinter maximum. The midsummer minimum of frequency is difficult to establish, except at high latitudes where continuous daylight eliminates the seeing of aurora, since the small number of night hours increases the relative importance of poor seeing conditions due to twilight and cloud. Since magnetic disturbances are also at maximum during the equinoctial periods, two possibilities exist, namely, an actual increase in the number of auroras corresponding to the increased magnetic disturbances at these times, or an increased tendency for the brighter auroras to spread to lower latitudes due to the increased magnetic disturbance. More extensive observations are required to decide.

Deduced diurnal variations often show great differences in the times of their principal maximum with location and even with the methods of handling the same data. The best established one is for position. At places distant from the auroral zone, auroras appear in the early evening hours in the part of the sky toward the zone, move toward the zenith as the night progresses and then move back again. Bright, active displays during periods of great auroral activity occur more frequently in the evening hours; quiet displays on these occasions in the morning hours. Often to correlate diurnal variations of aurora with magnetic disturbance an auroral character number for each hour, depending on brightness, activity, area of sky covered, etc., is determined. Since this character number depends partly on the observer's personal estimate of some of these quantities and partly on the weight attached to each one by the investigator, it is not surprising that the

resulting diurnal variations show large differences. Actually, observations are required for several years at a number of well-distributed places before any definite deductions can be made concerning characteristic diurnal variations for different localities. Vegard (16) from the diurnal variations at 5 places during 1882-83 suggested that the principal maximum occurs at the same local magnetic time, (time referred to the meridian passing through the geomagnetic pole), namely, about one hour before magnetic midnight. Observations (17) at a number of Canadian stations during 1932-33 do not offer much support to this suggestion.

The periodic characteristics of the aforementioned auroral variations are generally similar to periodic characteristics of some of the average features of magnetic storms. These are irregular disturbances of the earth's magnetic field, starting simultaneously everywhere and showing the greatest departures from normal close to the auroral zone. Corresponding similarities apparently exist between auroral and earth-current disturbances. However, attempts to correlate particular disturbances of the magnetic and earth-current records with visible aurora have not been very successful, cases occurring with bright aurora without any apparent effect on the magnetic and earth-current recorders. Conceivably the latter might be disturbed even when the aurora is too distant to be seen from the station, but the converse is difficult to explain, if aurora is more than a secondary manifestation of ionic conditions in the upper atmosphere.

Luminosity

The unusual and rapid changes of aurora give the impression of a greater luminosity than actually exists. All first-magnitude stars are readily visible through aurora. Only rarely does the illumination by a display on a horizontal surface approach that of the full moon. On occasion, bright, zenithal displays produce sufficient light to make newsprint readable. The photographically-effective illumination is generally less, since much of the auroral light is green, a colour to which photographic emulsions are relatively insensitive.

It is for these reasons that a photographic lens with a small f/number and very sensitive emulsions are required to photograph auroral forms without unduly prolonging the exposures. It is also the reason for the difficulties experienced in replacing eye observations by mechanical detectors. One method consists of moving a spectrographic plate at regular intervals and measuring the relative

changes in blackening due to the auroral green line. This method reduces some of the difficulties from twilight and moonlight, but can only record average conditions over the period of exposure. Another method consists of slowly moving photographic film past a narrow slit and using the variations in blackening. Photocells have also been used, but with little success. The new multiplier photocells, such as the one numbered 1P21, have increased the possibility of developing satisfactory detectors. Gartlein (18) has used such cells, and pulsed the incident illumination so that alternating current amplifiers can be used to detect the weak currents through the cell. A multiplier photocell recorder has been developed at the University of Saskatchewan, which uses a neutral wedge filter in front of the cell, the filter being moved by a servo-mechanism that is activated by a change in the potential drop across a resistance in the photocell circuit. The filter moves so that the illumination on the cell is a constant. The movement of the filter indicates the incidence of aurora; and its position the average intensity of the aurora in the section of the sky from which auroral radiation reaches the cell.

Position in Space

Investigations of auroral positions consist mostly of finding the heights and the orientations of the lower edges of various auroral forms. This is doubtless due to the greater luminosity close to the lower edge which makes it possible to determine its position with some accuracy on photographs.

The lower edges of quiet arcs and bands are usually more nearly parallel to the earth's surface than other forms. The majority have a lower limit between 100 and 110 km., a few above 130 km.; and a very few below 80 km. The absolute lower limit for active forms is also about 80 km., but lower limits of 200 km. and higher are not unusual. The observed upper limits show no systematic distribution of heights. For homogeneous arcs, they seldom get above 150 km.; but for rays, heights from 800 to over 1000 km. have been observed by Störmer. On occasion, rays extend into the sunlit part of the atmosphere. Whether or not there is a variation of heights with latitude is uncertain. Possibly the upper limit for rays increases with decreasing latitude.

Figure 3 shows the heights in miles of the lower edges of all quiet arcs and bands that have been measured in Canada. In general, heights were measured at about four different points along the base

of each, so that about this number of dots appear on the diagram for each band or arc. The grouping in the 60- to 70-mile range is quite apparent. The heights below 40 miles are from measurements made

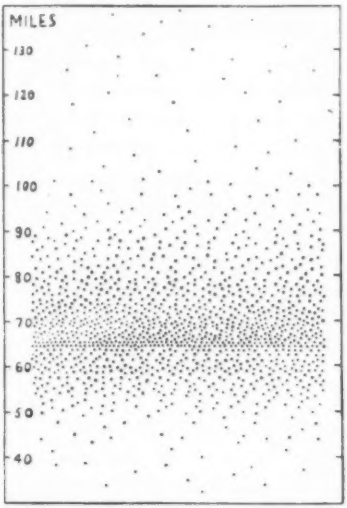

Fig. 3.—Heights in miles of the lower edges of all quiet arcs and bands which have been measured in Canada.

at Saskatoon in May, 1933 (8). These are the lowest heights that have been measured for aurora; but even so, they do not offer much support to the claims that auroras have been seen below clouds, or against some distant background, such as a mountain range, and that they are audible.

Figure 4 shows the average directions of quiet arcs and bands at a number of points across the northern part of North America. The directions are referred to the geomagnetic meridians. In general, the arc and bands are more nearly parallel to the geomagnetic lines of latitude than to the geographic lines of latitude.

The Auroral Spectrum

The usual yellowish-green tint of the aurora is due to a spectral radiation of wave-length, 5577.3 A, from atomic oxygen. Babcock first in the night-sky aurora and Vegard and Harang later in the polar

aurora determined this wave-length with great accuracy by interferometric methods. McLennan and his collaborators (19), working at the University of Toronto, demonstrated that a line of the same wave-

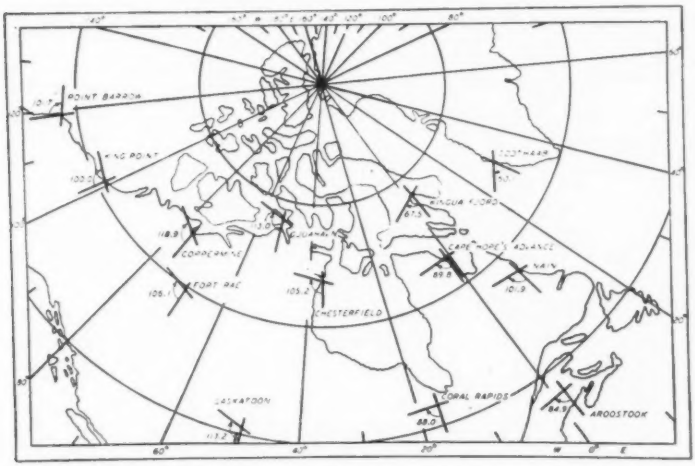

Fig. 4.—Average directions of quiet arcs and bands at points in northern part of North America.

length could be obtained by suitable electrical excitation of atomic oxygen, and that, (in terms of the spectroscopist), it is due to a forbidden transition between the low metastable terms $2p^4(^1D_2)$ and $2p^4(^1S_0)$ of the neutral oxygen atom. The successful identification of the green line led to the prediction in the auroral spectrum of three other oxygen lines at 6398, 6364 and 6300 A, due to the transitions OI $(^1D_2 - {}^3P_{0,1,2})$. The second and third are observed, and the last at least is subject to enhancement relative to the green line in sunlit aurora and at sunspot-maximum.

The other prominent parts of the auroral spectrum are readily identifiable with known spectra from nitrogen. Singly ionized nitrogen molecules emit a group of bands, the first negative bands ($^2\Sigma \rightarrow {}^2\Sigma$). Of these, the ones with heads at 3914, 4278 and 4708A occur with considerable intensity in the auroral spectrum. A number of bands of the neutral nitrogen molecule, called the second positive bands ($C^3\pi \rightarrow B^3\pi$), the first positive bands ($B^3\pi \rightarrow A^3\Sigma$) and the Vegard-Kaplan bands ($A^3\Sigma \rightarrow X^1\Sigma$), appear with decreasing relative intensities in the order named. Of these, the 2PG bands with wave-

lengths 3636, 3577, 3711, 3755, 3805, 3997, 4058 and 4345A and the 1PG bands with wave-lengths 5238, 5867 and 5991A are the ones appearing on the spectral plates after moderate exposures.

A number of other radiations have appeared on auroral spectrograms either after long exposures or with exceptional atmospheric conditions. The majority of these have been attributed to transitions of the ionized oxygen and nitrogen atoms. However, it is impossible at the present time to measure their wave-lengths with sufficient accuracy to be certain of these identifications, and the theoretical strengths of the possible emissions must be considered. Petrie (20) examined all possible transitions of ionized oxygen and nitrogen that might give lines that could be photographed. He concluded that some of these observed radiations are due to ionized oxygen and nitrogen, but pointed out that a number of theoretically strong lines from these atoms have never been observed. Spectral lines of hydrogen and helium have never been identified with certainty in auroral spectra.

Two associated problems, the excitation of the normal auroral spectrum in the laboratory and the energy exchanges responsible for the emission of the auroral radiations, have received much attention. Kaplan has been successful in exciting nitrogen bands that approximate in relative intensities to the ones appearing in aurora. Several possible mechanisms for the emission process have been deduced. In general, it is assumed that the night-sky aurora (auroral luminescence occurring at all latitudes), consisting of radiations from the neutral oxygen atom and nitrogen molecule, is produced by the recombination of oxygen atoms, the energy of dissociation exciting oxygen atoms and nitrogen molecules to states from which emission of radiation is possible. For the polar aurora, where the bands due to ionized nitrogen molecules are prominent, a much greater energy of excitation is required, and this is explained as due to the simultaneous ionization and excitation of the nitrogen molecules by the impact of corpuscles from without, which also excite oxygen atoms by impact to the metastable ^1S state and possibly to other excited states.

The temperature at auroral levels can be estimated from the Doppler broadening of the auroral green line, from the relative intensities of two lines due to transitions of ionized oxygen, and from the intensity-distribution within the vibrational bands of nitrogen. The intensity-distribution of the rotational lines in a band cannot be used directly because they are not separated by the spectrographs in use. Estimated temperatures range from about –40°C to several thousand

degrees. None of the temperatures obtained in this way are actually incorrect. They are a function of the excitation process and do not give the temperature that would be read on a thermometer at the auroral levels when the gases are in thermal equilibrium.

Causes of Aurora

The generally accepted cause of aurora is based on the aforementioned observations: (a) the variation of aurora with the sunspot cycle and the 27-day recurrence period; (b) the delay between visual evidence of solar activity and the occurrence of aurora; (c) the geographical distribution of aurora in relation to the earth's magnetic field; and (d) the occurrence of magnetically disturbed conditions with the appearance of aurora. The first indicates a solar agent, but does not distinguish between streams of corpuscles and bursts of ultra-violet light. The second indicates a corpuscular stream requiring a day or more to reach the earth and, from the geometry of the motion, entering the earth's atmosphere first on the side moving into darkness. The third indicates charged particles, since uncharged particles could penetrate the earth's magnetic field at all latitudes and auroras would appear more frequently at equatorial latitudes. The fourth is corroborative evidence of the arrival of the particles and of the ionization produced by them.

Störmer (see reference 4) investigated in great detail the trajectories of charged particles moving in the magnetic field around a uniformly magnetized sphere, and found that charged particles can penetrate close to the earth along narrow belts in the Arctic and Antarctic. The observed angular radii of the auroral zones required the assumption that the trajectories for equatorial latitudes consisted partly of a corpuscular ring current around the earth, the magnetic field of the ring modifying the motion of the particles reaching the auroral zones in such a way as to enlarge them.

These trajectories are determined by considering the motion of single particles, and not of a broad beam. Although they explain a number of the auroral forms in quite a remarkable way, two serious difficulties still exist. The first has to do with the dispersion of a beam of appreciable cross-section by the electrostatic repulsions of similarly charged particles, and the second with the energy required by a particle to penetrate the atmosphere to the depth where auroras are observed. The first can possibly be met by assuming either that the beam consists of particles that are neutral and become ionized on their

way to the earth or that the beam is ionized but electrically neutral. The second cannot be readily met even with particles like calcium atoms travelling at speeds of over 1600 km. per sec. (a speed suggested by the time interval between the passage of a spot across the sun's central meridian and the observation of aurora). It is also worth noting that streams of particles moving from the sun to the earth have never been detected.

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OUT OF OLD BOOKS

By Helen Sawyer Hogg

CATALOGUES OF NEBULOUS OBJECTS IN THE EIGHTEENTH CENTURY*

By Helen Sawyer Hogg

FOR the past two years I have been working on an extensive bibliographical compilation of globular clusters, listing all references to these under the individual globular cluster concerned. This work is in press, and will appear this fall.

During the course of this investigation, which was carried back to the very beginnings of the work on nebulous objects in the late seventeenth century, some interesting points came to light. One of these was a long-overlooked letter written by Pierre Méchain, published in Bode's Astronomische Jahrbuch für 1786. I am indebted to the Harvard Observatory for use of their copy of this rare book. This letter clears up a point in Messier's Catalogue which has puzzled astronomers for years. The part of the letter which concerns nebulae is reprinted here on page 272. The letter was unknown even to such diligent researchers into Messier's work as Gore,[1] Flammarion,[2] Shapley and Davis,[3] and Bailey,[4] all of whom have published identifications and comments on the catalogue.

In order to portray the development of the knowledge of nebulous objects, a brief account of the eighteenth century nebular catalogues will be given here.

The first attempt to list several nebulae together was made in 1715 by Edmond Halley, in the Philosophical Transactions of the Royal Society. This article, describing six objects, has been reprinted in this Journal, vol. 41, pp. 69-71, 1947. Several of these objects had been noted by observers other than Halley. In 1733, Derham published in the Philosophical Transactions a catalogue of

*Communications from the David Dunlap Observatory vol. 1, No. 14.

[1]*Obs.*, vol. 25, 1902. [2]*Bull. Soc. Astr. France*, vols. 31-35, 1917-21.

[3]*Ast. Soc. Pac., Pub.*, vol. 29, 1917. [4]*Ibid.*, p. 179.

16 nebulae which he had gleaned from the star catalogue by Hevelius (made without a telescope), published posthumously in 1690. Derham also mentioned the nebulous objects published by Halley. Derham's paper was translated into French and published by de Maupertuis in the Histoire des Académie royale des Sciences, Paris, 1734. I have republished Derham's paper in the July-August issue of this JOURNAL this year, and shown that only two of the sixteen objects he catalogued are now considered nebulous objects.

In 1755 the Abbé de Lacaille published, also in the Histoire de l'Académie royale des Sciences, his catalogue of 42 nebulae in the southern sky, *Sur les étoiles nébuleuses du ciel austral*. This catalogue was reprinted later several times in the French almanac, Connaissance des Temps, for 1783, 1784, and 1787. By using three Roman numerals, Lacaille combined an attempt at classification with the numbering of the object. He began his list with the great globular cluster 47 Tucanae as Lacaille I 1.

In the next decade, around 1746, the young Swiss astronomer, de Chéseaux, wrote a letter to his grandfather, M. de Réaumur, for the French Academy, with a list of 20 nebulae he had observed, some of which were his own discoveries. This letter was unpublished and almost unknown until found by Bigourdan, and published in the Paris Annales, Observations 1884, in 1891. The name of de Chéseaux is associated with the famous six-tailed comet of 1746. He was not the discoverer of this comet, but was the first to announce its many tails.

Publication of drawings of nebulous objects was begun by Le Gentil in the Mémoires of the Académie des Sciences in 1759.

It was in the 1760's that Messier began his discoveries of nebulous objects. The catalogue of Messier is to-day the most frequently mentioned of the early catalogues, probably because in its final form it included about the hundred most conspicuous nebulous objects in the sky (excluding the southern polar cap).

Charles Messier, born in 1730, went to Paris in 1751 without very much education, to be a draughtsman and copyist for the astronomer Delisle. Delisle seems to have been a person of singular jealousy, and Messier must have laboured in the early years under considerable handicap. Indeed Delisle refused to permit him to announce the return of Halley's comet when Messier first observed it on January 21, 1759!

After the death of Delisle in 1768, however, Messier rose to a high place in French astronomy, being elected to the Academy of Sciences in 1770, and appointed "Astronome de la Marine" in 1771, living at the Hotel de Cluny. He is best known for his work on comets and nebulae. Louis XV named him "le furet des comètes." He observed 46 comets, of which 21 were his own discoveries. He published works on other subjects, however, such as the transit of Venus in 1761 and the rings of Saturn. The famous Lalande so admired the work of Messier that he proposed, on his celestial globe of 1775, a constellation named Messier. This constellation was between Cepheus, Cassiopeia, and Camelopardalus. Messier lived to an advanced age, and died in 1817.

His first list of nebulae was published in the Mémoires of the Paris Academy of Sciences in 1771, *Catalogue des nébuleuses et des amas d'étoiles que l'on découvre parmi les étoiles fixes sur l'horizon de Paris*. This list contains 45 nebulous objects that Messier himself had found during his extensive work on comets. He does not attempt to make a catalogue of all known nebulous objects. A number of these nebulae are indicated on the maps of comet paths; in particular, the globular cluster Messier 2 is found on the path of the famous first-predicted return of Halley's comet in 1759.

The first person to combine all known nebulae into one uniform catalogue was Johann Bode of Berlin. In 1777, Bode published in his Astronomische Jahrbuch für 1779 a catalogue of 75 nebulae, entitled *Ueber einige neuentdeckte Nebelsterne und einem vollständigen Verzeichnisse der bisher bekannten*. This was the most ambitious catalogue then published, and merits more recognition than it has had. Bode included all the earlier works on nebulae by Halley, Hevelius, Derham, Lacaille, and Messier, as well as observations of his own. Bode's catalogue appears little known, possibly because the positions of the nebulae were given by zodiacal sign in celestial latitude and longitude, an outmoded method of designation which makes identification laborious.

After this compilation by Bode, Messier published another list in 1780, in the Connaissance des Temps for 1783. This list contains the first 68 objects of what is now known as Messier's Catalogue. The first 45 nebulae announced in the Mémoires for 1771 are reprinted with additional comments, and 23 more nebulae are added.

All of these objects were observed by Messier, and he was the original discoverer of most of them.

In 1781, in the Connaissance des Temps for 1784, Messier published new nebulae, numbered from 69 to 103, and this list was republished again in 1784, in the Connaissance for 1787. This last is the complete list, and is the document usually referred to as Messier's Catalogue.

However, most of these later nebulae were discovered not by Messier, but by Méchain, a young worker at the Bureau des Longitudes in Paris. Pierre François André Méchain was born in 1744 at Laon. He was employed as a calculator in the office of the navy. He had the reputation of an exact observer and an indefatigable calculator. After computing all day, he spent his nights observing. He entered the Academy of Sciences in 1782, after having co-operated in the determination of the difference in longitude between Paris and Greenwich. From 1786 to 1794 he edited the Connaissance des Temps. His later longitude work was broken off by an attack of yellow fever, and he died in 1805. Between 1781 and 1799 he discovered eight comets.

Méchain seems to be receiving far too little astronomical credit to-day for his work. The numerous histories of astronomy have almost nothing to say about him. But he discovered Encke's comet,[5] Tuttle's comet,[6] and one-fourth of the nebulous objects in Messier's Catalogue!

After Méchain discovered the later nebulae in the catalogue, Messier then in the course of a few weeks helped to determine a precise position for publication. In the final catalogue, however, the last three nebulae, Nos. 101, 102, and 103 are listed as objects seen by M. Méchain only. For Nos. 102 and 103 no precise position is given, but a description of the position only. Bode published this catalogue, Numbers 46 to 103, in 1783 in his Astronomische Jahrbuch für 1786. He published it in German, with his own comments, and noted especially cases where nebulae had been first discovered by observers other than Messier or Méchain.

Apparently after the final Connaissance des Temps list had gone to press, Méchain gathered together his last notes on nebulae, in-

[5]Chambers, A handbook of descriptive and practical astronomy, vol. I, p. 416, 1889.

[6]*Ibid.*, p. 430.

cluding corrections and additions, and sent them for publication in Bode's Jahrbuch. Toward the back of the same volume of the Jahrbuch containing the final catalogue (Jahrbuch für 1786), on page 232, is the letter from Méchain which has been overlooked for nearly a century. It clears up at once what has been a troublesome problem, namely the identification of the object No. 102.

Of the three last objects, Messier 101, 102, and 103, listed as seen by Méchain only, No. 101 is definitely identified as NGC 5457, the fine spiral in Ursa Major, and No. 103 is a galactic star cluster, NGC 581 in Cassiopeia. But the identification of No. 102 has given astronomers much perplexity. The printed description of it reads: "Nébuleuse entre les étoiles o du Bouvier et ι du Dragon: elle est très-foible; près d'elle est une étoile de la sixième grandeur".

Gore in 1902 commented that he had found no identification for No. 102. In 1917, with the publication of Messier's list by Shapley and Davis, Prof. Bailey of Harvard came to the conclusion that it was NGC 5866. The footnote in this article says, "Subsequent to Messier there appears to be no further mention of No. 102. 'By a star chart, or the sky, you will see that, taken as it stands, no object could well be selected for M 102, since o Boötis is too far from ι Draconis. If, however, o is a misprint for θ, it becomes intelligible and M 102 is perhaps N.G.C. 5866, although in Norton's Atlas it is apparently identified as N.G.C. 5879'."

Flammarion independently came to the same conclusion as Bailey, although he listed three other nebulae in the field which fitted the description almost as well. He says,[7] "J'ai eu la plus grande difficulté à identifier cette nébuleuse, et je ne suis pas absolument certain d'y être parvenu. Il y a près de cette position 3 nébuleuses . . . . C'est une véritable pépinière de nébuleuses!"

The question, however, was settled by Méchain himself in this letter in 1783, when he announced flatly that Nebula No. 102 was an error, and the same object as No. 101. I translate Méchain's statement as follows:

> On page 267 of the Connaissance des temps for 1784 M. Messier lists under No. 102 a nebula which I have discovered between o Bootes and ι Draconis; this is, however, an error. This nebula is one and the same as the preceding No. 101. M. Messier confused the same as the result of an error in the sky chart, in the list of my nebulous stars communicated to him.

[7] *Bull. Soc. Astr. France*, vol. 35, p. 287, 1921.

Therefore Messier 102 may now be stricken from the records as a non-existing object.

In this same letter, Méchain lists six additional nebulae which he has discovered, but which were not included in the Connaissance des Temps list. For two of these the remarks are too vague to permit certain identification. For four of them, however, identification is certain from the comments. In my opinion these should be added to the accepted list of Messier's catalogue as Nos. 104, 105, 106, and 107.

One of these nebulae on the southern boundary of Virgo has already been numbered by Flammarion. He found the object listed in Messier's own copy of his catalogue, in Messier's handwriting, as found by Méchain, and suggested that it should be listed as Messier 104. He says:[8]

"J'ai raconté que j'avais remarqué dans mon manuscrit du Catalogue de Messier une petite note, de la main de Messier, signalant que Méchain a découvert, le 11 mai 1781, une 'nébuleuse tres faible' dont la position était inscrite à AR 187° 9′ 42″ et D − 10° 24′ 49″.

. . . C'est la nébuleuse qui porte le n° 4594 de *New General Catalogue* de Dreyer. . . . Je l'ai donc ajoutée au Catalogue de Messier, et l'ai inscrite sous le titre *Messier 104*."

Obviously Flammarion, who did years of work on Messier's catalogue, did not know of this letter by Méchain in Bode's Jahrbuch. This object which he has identified is one of the four objects published therein. Although this nebula is the second mentioned in Méchain's letter, we will keep Flammarion's numbering, and assign No. 105 to the first nebula mentioned, discovered on the 24th of March 1781. This I identify as NGC 3379, one of a group of three spirals in Leo. The nebula "neben dem Stern No. 3 der Jagdhunde" is NGC 4258, a large spiral in Ursa Major, and should be Messier 106. In April 1782 Méchain discovered a little nebula "am linken Schenkel des Ophiuchus" which is NGC 6171, a bright, loose globular cluster in Ophiuchus, and should be assigned No. 107.

Data on these objects are given in Table I. All of them were found independently later by Sir William Herschel, and his catalogue numbers are included in the table. Herschel, too, must have overlooked this letter, since in his catalogues of nebulae he tried to list only his own discoveries and to avoid those found by other observers.

[8] *Bull. Soc. Astr. France*, vol. 35, pp. 334, 355, 1921.

TABLE I

Messier	NGC	R.A. 1900	Dec.	Discovery dates	
				Méchain	William Herschel
104	4594	$12^h\,34^m.8$	$-11°\,4'$	1781, May 11	1784, May 9, I 43
105	3379	$10^h\,42^m.6$	$+13°\,07'$	1781, March 24	1784, March 11, I 17
106	4258	$12^h\,14^m.0$	$+47°\,52'$	1781, July	1788, March 9, V 43
107	6171	$16^h\,26^m.9$	$-12°\,50'$	1782, April	1793, May 12, VI 40

DESCRIPTIONS

104 "7′ × 1′.5 in p.a. 92°; very bright. A remarkable, slightly curved, clear-cut dark lane runs along the entire length to the south of the nucleus; probably the finest known example of this phenomenon. There are very slight trace of spiral whorls." Curtis, *Lick Pub.*, vol. 13, 1918. Photo, Shapley, *Galaxies*, Fig. 66, 1944.

105 "This, with 3384 and 3389, forms a striking group, a right-angled triangle whose shorter sides are 7′ long. 3379 is nearly round, 2′ in diameter; very bright; no spiral structure discernible." Curtis, *Lick Pub.*, vol. 13, 1918.

106 "With the very faint extensions this spiral is nearly 20′ × 6′ in p.a. 165°; very bright, elongated nuclear portion, on the west of which is a short dark lane; there are numerous almost stellar condensations in the two principal spiral branches." Curtis, *Lick Pub.*, vol. 13. Photo, *Lick Pub.*, vol. 8, plate 33.

107 A bright globular cluster, with large angular diameter, but the stars are sparse and scattered. A chart of this cluster is published by Oosterhoff, *B. A. N.*, no. 310, 1938.

I am not aware of any discoveries of nebulae by either Messier or Méchain subsequent to this letter. When William Herschel entered the field of nebular sweeps, his discoveries so far outstripped all others that probably they made other astronomers feel that the few nebulae they might discover were hardly worth the effort. William Herschel's first *Catalogue of one thousand new nebulae and clusters of stars* was published in the Philosophical Transactions of the Royal Society, vol. 76, 1786, and was soon followed, in 1789, by the *Catalogue of a second thousand of new nebulae and clusters of stars: with a few introductory remarks on the construction of the heavens.* In 1802 he brought out his final *Catalogue of 500 new nebulae and clusters.* He did not number his nebulae consecutively, but attempted, as had Lacaille some years earlier, to classify them by appearance as he catalogued them. For a few objects this system is suitable, but for very many it soon becomes unwieldy, so that William Herschel's numbers are seldom used to-day.

After his death, his son John continued his work during the nineteenth century. John Herschel's first catalogue was published in the Philosophical Transactions, vol. 123, in 1833, *Observations on 2307 nebulae and clusters of stars made at Slough with a twenty-foot reflector between the years 1825 and 1833.* After this, John Herschel went down to the southern hemisphere in order to complete the work, and in 1847 published his famous catalogue, *Results of Observations at the Cape of Good Hope.* A copy of this rare book has recently been presented to the David Dunlap Observatory by courtesy of Sir Harold Spencer Jones, Astronomer Royal, on behalf of the Royal Astronomical Society. In 1864, John Herschel combined all existing data on nebulae and clusters in his well known *General Catalogue of nebulae and clusters of stars*, in the Philosophical Transactions, vol. 154, listing 5079 objects.

It is interesting to note that of the 99 clusters catalogued to-day as globular, William Herschel was the discoverer of exactly one-third, far outstripping his nearest rival. He found 33, James Dunlop (who catalogued the southern sky in the early nineteenth century) found 21; Messier 14; Méchain and John Herschel 5 each; Lacaille 4; and no other observer has found more than two.

All workers on nebulae and clusters must feel as Flammarion[9] did when he wrote, "La Terre tourne vraiment trop vite pour les contemplateurs de la nature, car ils ne sont jamais rassasiés."

Méchain's Letter

From Bode's "Astronomische Jahrbuch für das Jahr 1786," p. 231:—

Ueber die Bahn des zweiten Kometen vom Jahr 1781. Entdeckung einiger Nebelstern; die Elemente der Bahn des neuen Planeten und astronomische Beobachtungen; von Herrn Mechain in Paris, aus einem Schreiben desselben an Herrn Bernouilli, vom 6ten May 1783.

Was die Nebelsterne oder Nebelflecke anbetrift, so bin ich nicht im Stande Herrn *Bode* Verlangen völlig zu befriedigen, indem es mir bis jetzt an Zeit gefehlt, die genaue Stellung aller derjenigen die ich entdeckte habe, bestimmen zu können. Ich will daher nur die Oerter von einigen, die sich nicht in der Connoissance des tems f. 1784 befinden, angeben, und werde die übrigen so anzeigen, dass man sie wird auffinden können.*) Herr *Messier* erwehnt daselbst Seite 264 und 265 zweyer

*S. das Verzeichniss der von den Herren Messier und Mechain seit 1771 beobachteten Nebelsterne. Seite 164.

[9] *Bull. Soc. Astr. France*, vol. 31, p. 386, 1917.

Nebelsterne, welche ich im Löwen entdeckt habe. Ich finde bey den angegebenen Stellungen die ich durch Vergleichung ihres Standes gegen Regulus bestimmt habe, nichts auszusetzen. Es befindet sich aber noch ein dritter etwas nordlicher, der zugleich lebhafter wie die beyden vorhergehenden ist. Ich entdeckte denselben am 24sten März 1781, 4 oder 5 Tage nachdem ich die beyden andern gefunden. Den 10ten April verglich ich seinen Stand mit $\gamma\ \Omega$ woraus sich seine gerade Aufsteigung 159° 3′ 45″ und seine nordliche Abweichung 13° 43′ 58″ ergab.

Seite 267 der Connoissance des tems f. 1784 zeigt Herr Messier unter No. 102 einen Nebelfleck an, den ich zwischen o Bootes und ι Drachen entdeckt habe; dies is aber ein Fehler. Dieset Nebelfleck ist mit dem vorhergehenden No. 101 ein und derselbe. Herr Messier hat durch einen Fehler in den Himmelscharten veranlasst, denselben nach dem ihm mitgetheilten Verzeichnisse meiner Nebelsterne verwechselt.

Den 11. May 1781 entdeckte ich einen Nebelfleck übern Raben, der mir keine einzelne Sterne zu enthalten schien. Er ist von einem schwachen Lichte und schwer zu finden wenn man die Fäden des Mikrometers erleuchtet. Ich habe ihn an diesem Tage und den folgenden mit der Spica in der Jungfrau verglichen und hieraus die gerade Aufsteigung 187° 9′ 42″ die südliche Abweichung 10° 24′49″ gefolgert. Er steht nicht in der Connoissance des tems.

Seite 262 und 263 erwehnt Herr Messier verschiedene Nebelflecke in der Jungfrau, die ich ihm angezeigt habe. Es befinden sich aber in der dortigen Gegend noch einige andere, die er nicht gesehen, und deren Lage ich zu bestimmen gedenke, wenn ich erst einen bequemen Beobachtungsort habe, welches sich nicht lange mehr verzögern wird.

Seite 265 No. 97. Ein Nebelfleck nahe bey β im grossen Bären. Herr Messier erwehnt, bey der Anzeige seiner Stellung, zween andere, welche ich gleichfalls entdeckt und wovon der eine nahe bey diesem, der andere nahe bey γ im grossen Bären sich befindet, ich habe aber ihre Oerter noch nicht bestimmen können.

Im Julii 1781 fand ich einen andern Nebelfleck nahe beym grossen Bären neben dem Stern No. 3 der Jagdhunde und 1° südlicher, ich schätzte seine gerade Aufsteigung 181° 40′ und seine nordliche Abweichung ohngefehr 49°. Ich werde nächstens die genauere Stellung desselben zu bestimmen suchen.

Im April 1782 entdeckte ich einen kleinen Nebelfleck am linken Schenkel des Ophiuchus zwischen den Sternen ζ und ϕ, dessen Ort ich noch nicht näher beobachtet habe.

Dies ist ausserdem, was in der erwehnten Connoissance des tems verkömmt, alles was ich wegen der Nebelsterne gethan habe. Ich werde darüber ein besonderes Memoire ausfertigen und ihre Oerter und Erscheinungen, näher bestimmen.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Synodic Period of Mars

The synodic period of a planet is the interval between two successive times when the planet occupies the same position in relation to the sun as seen from the earth, for instance, from opposition to opposition. The sidereal period is the time of its revolution round the sun, from a star to the same star again, as seen from the sun, i.e., the true mechanical period of revolution of the planet. In the case of Mars the sidereal period is 687 days, the synodic period 780 days. But if we are given the date of an opposition and add 780 days to it in the hope of finding the date of the next one, we may obtain a result far from the actual time. In facts the interval between successive oppositions may vary from 765 to 811 days, i.e., 15 days less to 31 days more than the mean value.

In an essay on Mars by C. J. Westland of Christchurch, N.Z., which the present writer was privileged to examine through the courtesy of our friend, A. V. Madge of Montreal, there is given a simple formula for calculating approximately the number of day, from one opposition to the next. It is given in the simple equation,

$$y = 811 - 0.27x,$$

in which x is the number of days between the date of an opposition

Oppositions of Mars, 1900–1950

Date	S	x	y	Date	S	x	y
1901—Feb. 22.....	765	144	772	1926—Nov. 4.....	778	111	781
1903—Mar. 29.....	771	109	782	1928—Dec. 21.....	767	158	768
1905—May 8.....	789	69	792	1931—Jan. 27.....	764	170	765
1907—July 6.....	811	10	808	1933—Mar. 1.....	766	137	774
1909—Sept. 24.....	791	70	792	1935—Apr. 6.....	774	101	784
1911—Nov. 25.....	775	132	775	1937—May 19.....	795	58	795
1914—Jan. 5.....	765	173	764	1939—July 23.....	810	7	809
1916—Feb. 9.....	765	158	768	1941—Oct. 10.....	786	86	788
1918—Mar. 15.....	768	123	778	1943—Dec. 5.....	770	142	773
1920—Apr. 21.....	779	86	788	1946—Jan. 13.....	765	181	762
1922—June 10.....	806	36	801	1948—Feb. 17.....	765	150	771
1924—Aug. 23.....	803	38	801	1950—Mar. 23.....	...	...	...

and the nearest July 16, before or after the date; and y is the number of days to the next opposition.

It will be interesting to compare the values obtained from this formula with those actually observed. They are exhibited in the accompanying table.

In the above table we have first the dates of the oppositions from 1900 onwards. The first three are taken from the *Nautical Almanac*, and the rest, excepting the very last entry, are from the OBSERVER'S HANDBOOK which, of course, owes them originally to the *Almanac*. The last date is from the values of heliocentric longitudes of the planets published by the *Nautical Almanac* office. In the column headed S are the successive synodic periods, obtained by subtracting the date from the next following one. In the other two columns x and y have the meanings given above. It will be noted that the longest synodic periods are for oppositions occurring in the middle of the year, the shortest for those near its beginning.

C. A. C.

MEETINGS OF THE SOCIETY

AT EDMONTON

February 10, 1946.—It was announced that the next meeting would be devoted to a paper on the Calendar and Calendar Reform, followed by consideration of a resolution regarding a proposed world calendar.

Dr. Campbell read a tribute to Mr. Cyril G. Wates, and the audience stood for a minute to honour his memory.

After some discussion of some form of memorial it was moved by Dr. Campbell, seconded by Mr. Montgomery, that a committee of three be appointed to consider suggestions, and to make a recommendation at a future meeting. Carried.

Mr. Carscadden gave a short talk on the meaning of the parsec, a unit of distance at which the radius of the earth's orbit would subtend an angle of one second of arc.

The main paper of the evening was by Mr. R. Jacka on the subject "Meteorology and Commercial Flying."

Knowledge of the present and future weather along the route of any proposed flight is very important. To make a forecast various facts are observed at many stations, and reports sent by a special code to some central office. Clouds are judged by eye. Precipitation is measured, and is classified as rain, snow, hail, drizzle, freezing rain or drizzle. Visibility is estimated by known landmarks, and is important for landing. Air pressure is measured by the barometer, and is reduced to millibars for sea level to eliminate the effect of the altitude of the observing station. Temperature is given to the nearest degree Fahrenheit. The dew point is determined by observations of a wet-bulb thermometer. Wind velocity is another condition important for landing.

Explanations and illustrations were given of the making of a weather map summarizing all these observations. The way in which a forecaster would use such a map was described, and reference was made to his difficulties.

March 14, 1946.—President Dr. Wyman occupied the chair.

Dr. Campbell reported for the Memorial Committee to effect that recommended (1) enlarging and framing a photo from Mrs. Wates, same to be hung in Observatory; (2) inscribed plate be put on telescope recording date, etc., of Mr. Wates' gift.

Dr. Campbell referred to Mr. Wates' lens-grinding machine. Mr. Mjolsness and a friend have set up this machine at the University of Alberta, and it might be demonstrated after the meeting. Use of this machine would further commemorate Mr. Wates.

Mr. Keeping, Librarian, reported the gift of Mr. Wates' books to the Society, by Mrs. Wates; also charts and photos that would make most welcome and valued additions to the library.

Illness of Mr. Fosvedt necessitated his paper being read by Mr. Keeping. The movement for calendar change began in the United States in 1916 as part of a tendency to industrial reform. Attempts to divide time conveniently led to the use of the earth's motion as basic rule. The seasons were a natural division, as were the moon's phases. The tropical year, month, week, days of the week, were explained in origin and meaning. Lack of agreement among these divisions led to attempts to patch up calendar, most of these being made by pontiffs. Julian calendar corrected errors to date, and allowed for Leap Year. Augustus Caesar made further variations, leaving February as it is to-day. By 1582 the calendar was eleven days out of step with the seasons so Pope Gregory made a revision, making century years divisible by 400 as Leap Years. England in 1752 adopted Gregory's Calendar; Russia in the 20th century. Present error is one day in 20,000 years.

Although the length of calendar year agrees with the length of solar year, 14 yearly patterns occur, so a new calendar must be used each year. Uneven lengths of months, of quarters, of half years, are very confusing and costly. Statisticians, accountants, financiers, educationists, etc., all demand more uniformity.

Stability and equalized time divisions are needed. Two suggestions: (1) a 13-month calendar, all of 28 days, every month beginning on Sunday. One extra day each year, and two on leap years. New month would be needed, perhaps "Sol," between June and July. Year-days would not be incorporated in week. (2) World calendar, 12 months, 4 equal quarters 31-30-30 days. Again one extra year-day, and two for leap year, without date attached. All yearly and quarterly calendars begin on Sunday.

World calendar more popular, less revolutionary. More like present calendar. Could be introduced in 1950, when January 1 falls on Sunday. Most religious groups favour reform, even Pope Gregory favouring a fixed Easter when calendar reform was under consideration. Unity would be encouraged by a world celebration of holy days like Easter at one period. Seems a task for U.N.O. Slowness of movement stressed by Mr. Keeping, who had delivered similar paper in 1933, hoping for adoption in 1933 or perhaps 1939.

April 11, 1946.—The main paper of the evening was given by Dr. E. H. Gowan on the subject, "Atomic Energy and Stars." The concepts of the molecule and the atom have arisen by thought about the process of subdividing matter, and whether this could be continued indefinitely. Mental pictures or models have been conceived, and gradually made to fit the evidence available from experiment. A very useful atomic model is an analogue of the solar system, a massive positive core or nucleus corresponding to the sun, and lighter negative electrons corresponding to the planets. Chemical reactions, light, and X-rays for example, result from energy changes among these electrons.

Radioactive behaviour, on the other hand, is the result of changes in the nucleus itself. Natural transmutations take place this way, but any transmutation, natural or artificial, involves changes in the nuclei of atoms. In most cases the energy obtained is very small compared with the energy needed to start the process, but in a few cases more comes out than is put in.

The connection with stars arises from attempts to explain the source of stellar

energy, particularly in the sun, our nearest and best known star. No theory except that of the changing of mass into energy has been able to allow the sun a long enough life to agree with the evidence of geology. The carbon cycle is a possible series of reactions giving the net result of transforming hydrogen into helium and energy. It is probable that novae are caused by some set of conditions starting a nuclear chain reaction.

May 11, 1940.—The report of the Memorial Committee was given by Dr. Campbell. Two photographs of Mr. Wates were shown, one with his telescope and observatory on the river bank opposite his home. This will be hung in the same observatory, now situated on the University grounds. The second photograph, a portrait of Mr. Wates taken a few years ago, will be hung in the main observatory along with the brass engraving telling of his gift of the telescope. The clock drive for the main telescope has been finally installed.

The main paper was given by Dr. J. A. Pearce, of the Dominion Astrophysical Observatory in Victoria. The speaker referred to Spectral studies of a Wolf-Rayet star by Miss Jean McDonald, whom many members will remember. He summarized the data studied by Mr. Keeping during last summer. There is great interest among astronomers in binary systems where temperatures up to 100,000°, and luminosities several thousand times that of the sun have been observed.

The speaker then outlined the work he has recently done on the Pleiades cluster, for which 200 plates have already been measured. Visual observation shows 7 or 11 stars if the night is very clear and moonless, but 500 stars can be counted by photography. There has been some difficulty explaining the origin of the name but it seems clear now that the stars were considered to be Daughters of Pleione in Greek legend. Literature is full of references to this cluster. Dr. Pearce has checked back on the observations made by Hipparchus and showed these to be extraordinarily accurate. Studies made of the stars in this cluster, their motions, and their distances, help to decide which are really in the cluster and which are only there because they are in the same line of sight. These studies also show that many of the stars in this cluster are several hundred times as bright as the sun.

October 10, 1940.—The main paper, on The Aurora, was by Mr. A. J. Filmer. The various visible forms were described. Rays may be single or in bundles, or giving the appearance of a drapery. Arcs are mainly homogeneous. There may be slow or rapid motion in both types. Measurements show that aurora occur mainly around 105 km. in height, except for sunlit aurora, which are most prevalent around 400 km.

There have been many reports of aurora occuring between observers and distant mountains. There is usually some other explanation possible when trained observers are reporting. Auroras have been reported as audible. The explanation seems to be that things are heard at the same time, and may be associated electrically but may not be associated directly. A definite connection with sunspots is shown by the observations.

Explanations of the primary effect by various thories of charged particles from the sun were described, and their partial success noted. The ultra-violet

light theory was explained, and its partial success noted. The conclusion was reached that there is still much work to be done in clearing up the real and complete cause of the various auroral displays.

November 14, 1946.—The main paper, on "Rockets," was given by Mr. T. M. Carscadden. All rocket action is based on Newton's third law of motion: To every action there is an equal and opposite reaction. Both earth bound and interplanetary space rockets were considered. Analogies such as jumping out of a boat were used to help illustrate the principles.

Meteorological rockets are now being tried for collecting samples of air, and to observe pressures and temperatures. They rise to about 48,000 feet under power, then go to to 85,000 feet before stopping and falling back.

Space rockets need better engines and fuel than are now available. They would travel in elliptical paths and it might be possible to circle the moon or even land in it. Getting back again would then be a large undertaking.

A satellite rocket circling the earth was suggested as a useful laboratory, as well as a "dock" for space ships. Is this too far fetched? There seem to be no theoretical barriers, but many engineering obstacles to overcome before any space travel is possible.

January 9, 1947.—The secretary read the announcement of the 25th anniversary celebrations held by the London Centre, and the letter of congratulations which had been sent in the name of the Edmonton Centre.

The main paper of the evening was given by Miss Sidney Jones on the subject of "Jupiter." Jupiter is larger than all the other planets combined, has about one thousandth the mass of the sun, and is about one quarter the density of the earth. The orbital speed is about 8 miles per second, but the rotation is rapid, a day being only 10 hours long.

There are zones and markings of various colours on the surface of the planet. Some are fairly permanent, others change rapidly. Observation of these markings show differences in rotation time, and indicate that we see only the planet's atmosphere.

The spectrum of Jupiter shows the characteristics of sunlight with modifications due to absorption in its own atmosphere superimposed.

The first observation of Jupiter's satellites was made by Galileo in 1610. Analysis of their periods of revolution by Roemer led to one of the first measurements of the speed of light. There is also a family of 32 comets associated with the planet.

After a period for questions and discussion the meeting adjourned at 9.40 for refreshments. There were 23 members and visitors present.

February 13, 1947.—A letter from Montreal was read asking about our relationships with the University here. It was moved by Dr. Campbell and seconded by Mr. Montgomery that a letter be sent describing our arrangements.

Don Sanderlin, 11305-92 St., Edmonton, was elected a member of the Society.

The main paper of the evening was given by Mr. E. S. Keeping, whose topic was "The Discovery of Neptune." It is almost exactly one hundred years since

Neptune was discovered, in dramatic circumstances that make this event one of the most interesting in the annals of astronomy.

Sir William Herschel had discovered Uranus in 1781, and it had since been carefully studied. Old observations had also been found, one as long ago as 1690, and an orbit was computed by Bouvard. Discrepancies appeared, however, and by 1840 were increasing rapidly. Two men, John Couch Adams in Cambridge, England, and Urbain Leverrier in France, set themselves, quite independently, to discover the cause of these discrepancies. Both postulated the existence of an unknown planet and set themselves the extremely difficult task of computing from the observations on Uranus the position and mass of the suspected planet. In 1845, Adams tried to see Airy, the Astronomer Royal, and communicate his results, but they failed to meet. Airy, however, had an abstract of these results, but pigeonholed them. Meanwhile, Leverrier communicated his preliminary results to the French Academy, and Airy was then struck by the agreement between the two predictions. He asked Challis at Cambridge to search for the planet, and the search began on July 29, 1846. The planet was actually observed four times before the end of September, but not recognized.

Leverrier completed his work and in September asked Galle at Berlin to search. Galle had the advantage of a new star-chart, and found the planet the first night, September 23, 1846.

A bitter controversy was started as to whether Adams should receive any credit for his work. The French even wished to name the new planet "Leverrier," which would involve re-naming Uranus as "Herschel," but this soon was dropped. The consensus of opinion now is that both Adams and Leverrier deserve equal credit, but that Leverrier was the more fortunate in the person of his observer. Some eighty years later another planet, Pluto, was added to the solar system in a somewhat similar manner. The mass of Pluto is, however, so small that it seems doubtful whether the perturbations due to it can actually be detected. There was probably a considerable element of luck in the verification of Lowell's predictions by Tombaugh.

March 13, 1947.—Mr. Turner, 20 James Richardson Building, Jasper Ave., Edmonton, was elected a member of the Society.

The main paper of the evening was given by Mr. W. E. Mjolsness on the subject of the Making and Testing of amateur reflecting telescopes.

He described the laboratory which is being organized in the basement of the Mathematics Building. The hope was expressed that members would make use of the facilities. The technique of rough grinding, find grinding and polishing were described in detail. The reasons for the "figuring" and the use of the knife-edge test were described. This test is used many times to keep track of the way in which the shape of the mirror surface changes as the work progresses.

There were 19 members and visitors present.

E. H. Gowan, *Hon. Secretary.*

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THE DETONATING FIREBALL OF 1946, JUNE 1-2

By WILLIAM BUSCOMBE

THROUGHOUT southern Saskatchewan a very bright fireball was observed just after midnight Sunday morning, 1946, June 2, at approximately 12:40 a.m., Mountain Standard Time. It was first reported in letters from the Rev. Thos. W. Bray of Tuxford and Mrs. Eugene Quintin of Antelope, which arrived during my absence from the University on holidays. Their descriptions obviously referred to the same meteor, and indicated from the intersection of the two lines of sight that it disappeared over the vicinity of Assiniboia and Wood Mountain. A student in my summer class, N. J. W. Sherman, who is a teacher at Rockglen, recalled having heard reports which confirmed this general area. Another of my students, G. M. Krislock, a teacher at Riverhurst, referred me to the local editor, Mr. Fred T. Hill, who produced clippings from his *Weekly Courier* giving reports from several of his readers. This indicated that interest in the meteor was sufficiently widespread to warrant a general appeal for observations, even six weeks or more after the phenomenon. Accordingly I wrote to several of the papers serving that section of the province. Gradually a few replies came, and when all leads to people who had taken particular notice of the meteor were followed up, a total of eleven independent eyewitness reports was collected. These are abstracted in Table I. The weekly press was most helpful, and the aforementioned Mr. Sherman very kindly interviewed the two observers from Scout Lake. Unfortunately a trip to interview other eyewitnesses to obtain further details

TABLE I. OBSERVATIONS

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Mrs. Eugene Quintin, Antelope	108°20′	50°09′	160	30	140	10	32	16
Rev. Thos. W. Bray, Tuxford	105 34	50 36	220	20	200	15	43	16
J. Gibson, B. Gibson, C. Shooter, Riverhurst	106 54	50 56			140	10		14
E. P. Ayers, Demaine	107 13	50 43	190	15	150	10	25	14
G. V. Dahlberg, Moose Jaw (at Spring Valley)	105 21	49 57	260	25	260	15	48	12
Mrs. O. E. Wilson,†Limerick	106 16	49 39	250		310	50		19
A. R. Herron,*Coderre(6 mi. s.w. of Mortlach)	106 10	50 23			195	0		
George Staseson, Flintoft	106 21	49 28	280					
Walter Merrett, Wide View; Ronald Merrett,* Mankota (at Wide View)	107 06	49 15	325		050			
Marian Pilsner, Mrs. V. Scheltgen, Scout Lake (5 mi. north of Rockglen)	105 57	49 15	310		330	20		16
Mrs. W. G. Turner, Braddock	107 23	50 06	190	40	110	15	33	13

Legend:
(1) Name and address of observer, with point of observation in brackets.
(2) Longitude of point of observation, west of Greenwich (λ).
(3) Latitude of point of observation, north of equator (ϕ).
(4) Azimuth when first seen, degrees from north through east (A_1).
(5) Elevation when first seen, degrees above horizon (h_1).
(6) Azimuth when last seen (A_2).
(7) Elevation when last seen (h_2).
(8) Computed height of first luminosity, in miles (H_1).
(9) Computed height of disappearance (H_2).
†In house.
*Driving car on straight road.

and to improve the accuracy of the observational data was not feasible, although much information could have been gleaned from people who did not report by mail. None of the observers used stars or planets as reference points for describing the meteor's path.

DESCRIPTION OF METEOR

All of the six observers who described the meteor's colour referred to it as bluish-white, causing a brilliant "fluorescent" illum-

ination of the landscape like the moon when not quite full. This suggests an apparent magnitude around −10. From this and the computed height on disappearance, it would seem just barely possible that meteoritic fragments might be recoverable. One or two sharp-eyed observers mentioned a reddish-yellow cone of light following the main flash for a few seconds, and others suggest that instead of disappearing suddenly, the light faded into a shower of sparks. No significant estimates of the diameter were obtained, and no enduring train was reported.

Detonations

At the places indicated by triangles on the sketch map (fig. 1), various detonations were heard. Windows rattled at Shamrock and Coderre, owing to atmospheric compression waves, which were accompanied by a low rumble. At Wide View, "the explosion shook the house three distinct times." This suggests several minor disruptions of the meteoric mass. The fullest account of sound effects is from Flintoft, where a long, low rumbling sound was first heard from the west-northwest about 3-4 minutes after the flash. The sound increased in volume to the terrifying proportions of a stampede of thousands of cattle, then gradually faded away. After another minute or so the rumble started again for a short time. Apparently this auditor heard the thunderous expansion of the air along the path which had been heated by the meteor's passage, due to friction. The sound from farther back along the path would take longer to reach his ear at a velocity near 12 miles per minute. If the elapsed time between the flash and sound were more accurately known, one might be able to determine from the interval the atmospheric temperature at a height greater than that attained by meteorological sounding balloons or aircraft.

Weather Conditions

According to Dr. T. G. How, meteorologist-in-charge at Edmonton Airport, the southwestern Saskatchewan area was clear of clouds at the time, with no restriction to visibility. At Regina the sky was overcast with a thin layer of altocumulus cloud at about 10,000 feet above the ground, of which patches extending as far west as Moose Jaw were mentioned in the Tuxford report. No one else mentioned the presence of any clouds, although several had a

first impression that the meteor flash was lightning out of a clear sky. North of the district the cloud was thicker, and a light rain was falling at Saskatoon. The whole central part of the continent

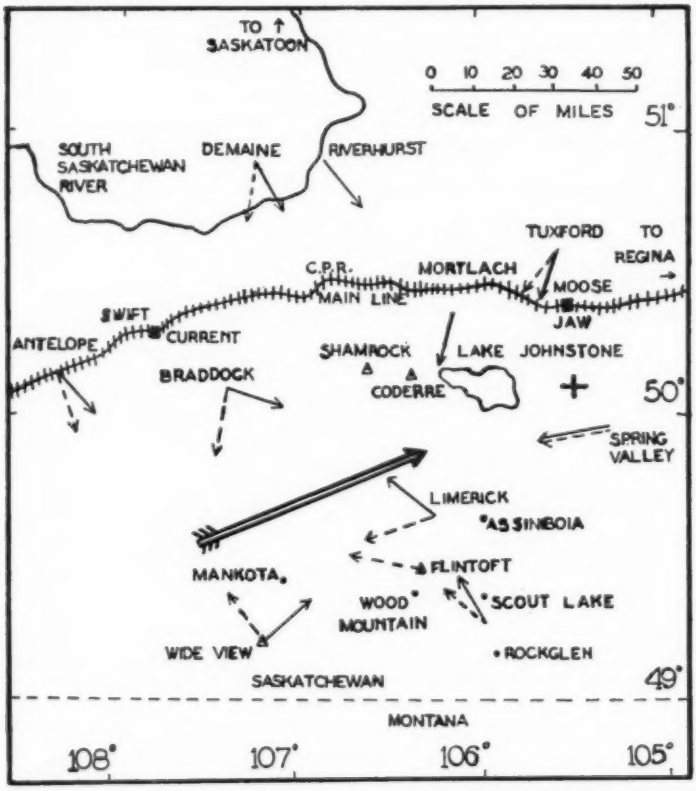

Figure 1. Region through which the meteor was visible. Triangles indicate places where detonations were reported. Dashed arrows, lines of sight to point where meteor was first seen; short solid arrows, lines of sight to where it disappeared. Double solid arrow, horizontal projection of meteor's path; cross, computed earth-point.

was covered by a conditionally unstable Polar continental airmass in a vast anticyclone centred at Winnipeg. To the east of a stationary front along the Rockies there was a fairly solid rain area

through Alberta, with thunderstorms in the southern portion, where the orographic effect of rising ground in the foothills provided the extra lift needed to release the latent instability of the moist air. However the nearest thunderstorm was over 300 miles from the region in which the meteor was seen, so the sound of thunder could not travel that distance.

Determination of Path

On the sketch map of the region (fig. 1) arrows indicate the lines of sight toward where the meteor first appeared and finally disappeared, as seen from various locations. On a working diagram these arrows were projected to find where they intersected. However the beginning and end points of the meteor's path were not uniquely determined, as all the arrows did not exactly meet in a point. Circles of minimum radius were drawn just to enclose all the intersections, and their centres were adopted as the beginning and end points. The radii of the circles of confusion are 17 and 10 miles respectively. The point of first luminosity is usually less accurately determined, as different intervals of time elapse before each observer's attention is focussed on a meteor flash. Seven observations placed the beginning point at longitude $\lambda_1 = 107°32'$W, latitude $\phi_1 = 49°33'$N; while from eight reports the end point was determined as $\lambda_2 = 106°19'$W, $\phi_2 = 49°53'$N. Thus the meteor was seen to travel from above a point 15 miles south of Ponteix to about 2 miles east of Palmer. The projected path, 59 miles long, is shown by a double arrow.

If we consider for the moment a small region of the earth's surface as the tangent plane to a sphere (fig. 2), we may select rectangular Cartesian co-ordinate axes Ox eastward and Oy northward from the beginning point. If $\Delta\lambda$ and $\Delta\phi$, the changes in longitude and latitude along the visible path, are expressed in radian measure, and R is the radius of the earth, we have

$$\Delta x = R\Delta\lambda \cos \tfrac{1}{2}(\phi_1 + \phi_2) = 54 \text{ miles},$$
$$\Delta y = R\Delta\phi = 23 \text{ miles}.$$

The azimuth of the projected path is $A = \tan^{-1}(\Delta x/\Delta y)$, i.e. toward N 66° E.

The degree of uncertainty of this computation is due to enforced reliance on reports of observers without special training, as recalled from memory several weeks after the event. As even such rough

estimates are reasonably consistent, continuation of the analysis seems justified, but the results will not warrant screening by more precise statistical methods.

Heights

From each observation of the elevation of the beginning or end point of the luminous trail, including the small correction for refraction, the corresponding height of the meteor was computed. (Table I, columns 8 and 9.) It is easily seen that

$$H = d \tan h' + \frac{d^2}{2R} \text{ (approximately),}$$

where H = height in miles;
d = observer's distance from initial or final point on projected path, in miles, measured on map;
h' = observed elevation, corrected for refraction;
R = radius of earth, 3960 miles.

The last term is a small correction for the dip of the horizon, due to the curvature of the earth. For simplicity, the visible path is taken as a straight line, although under gravity a parabolic trajectory would be slightly more exact. As the Tuxford, Spring Valley and Braddock observations appeared somewhat more reliable and precise, double weight was assigned to them in averaging the heights. The mean height of first appearance is $H_1 = 38 \pm 2.3$ miles, and of last appearance $H_2 = 15 \pm 0.5$ miles. These values seem remarkably low, but McIntosh[1] finds that for slow sporadic fireballs like this, the height of disappearance averages lower than for any other class of meteor. In view of the meteor's slow speed (referred to later) and its oblique angle of approach, the low height of appearance may not be considered unreasonable. The vertical drop component of the visible path is $\Delta H = 23$ miles. From Pythagorean relations in right-angled triangles we have $P^2 = \Delta H^2 + \Delta x^2 + \Delta y^2$, where P, the true length of the luminous path, is 64 miles. The path is inclined to the horizontal at an angle

$$i = \sin^{-1}(\Delta H/P) = 21°.$$

[1]R. A. McIntosh, *J.R.A.S.C. vol. 37*, 308 (1943).

Earth Point

Next comes the determination of the earth point, where the extension of the meteor's luminous path intersects the earth's surface. It is easily seem from similar triangles (fig. 2) that the components of distance east and north respectively from the end point to the earth point are $\Delta x' = H_2(\Delta x/\Delta H) = 35$ miles and $\Delta y' = H_2(\Delta y/\Delta H) = 15$ miles. As no one reported sudden changes in the meteor's direction of flight, it may safely be assumed that no major deviation of path occurred, so that any possible meteorites which survived combustion should be sought near the earth point, $\lambda' = 105°32'$W, $\phi' = 50°06'$N, about 6 miles east of Crestwynd

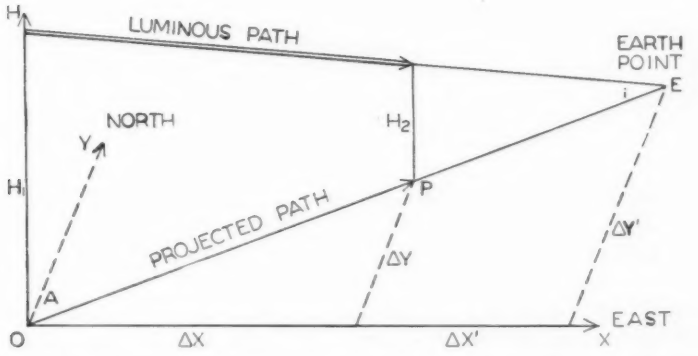

Figure 2. Schematic representation of meteor's path in three dimensions. Origin O is taken vertically below point where meteor was first seen. Axis Ox is eastward on earth's surface, Oy northward, OH vertically upward. The line OPE is common to the horizontal plane EPOx and the vertical plane HOPE in which the meteor fell.

or 20 miles due south of Moose Jaw. Residents of this area have been asked to report any likely objects, but to date no specimen of meteoric origin has been submitted or described. The terrain of all this district ranges in elevation from 1800 to 2400 feet above sea level, sloping upward through the Wood Mountain area toward the south-west corner of the province. The accuracy of observations does not warrant any adjustment for elevations of this order.

Velocity

Only three observers ventured estimates of the duration of the meteor flash, averaging slightly over 3 seconds. From this the observed velocity (w) through the lower atmosphere would be in the neighbourhood of 20 mi./sec., which is reasonable for an object overtaking the earth from the west in its axial rotation. A correction for the earth's attraction must be made to determine the actual (geocentric) space velocity, u, from the relation[2] $u^2 = w^2 - 2gR$, where g is the acceleration due to gravity in miles per second per second, and R is again the earth's radius. This gives $u = 18.8$ mi./sec., which is verified from a table constructed from this relation.[3]

Since the meteor's path has curved from the asymptotic path along which it was approaching the earth, due to the earth's gravitational attraction, we may compute the true zenith distance (ζ) from which the meteor entered the atmosphere. If $z = 90° - i = 69°$ is the observed zenith distance we have[4]

$$\tan \tfrac{1}{2}(\zeta - z) = \frac{w - u}{w + u} \tan \tfrac{1}{2} z.$$

Hence $\zeta - z = 2°.5$, which checks with the table[5] if $\log (u/w)$ is used as argument; and $\zeta = 71°.5$. This table also gives the apparent elongation of the radiant from the apex of the earth's way, $e = 88°$. By vector addition,[3] $M^2 = E^2 + u^2 - 2uE \cos e$, where E is the earth's orbital velocity, 18.5 mi./sec., we obtain the heliocentric velocity $M = 25.9$ mi./sec. As M is slightly less than $\sqrt{2}\,E$ (the parabolic velocity), the orbit in space must have been an elongated ellipse.

Radiant

The radiant is the direction in space from which the meteor approached the earth. Its co-ordinates on the horizon system are zenith distance $\zeta = 71°.5$ and azimuth $A = 66°$ from south toward the west. By spherical trigonometry we transform to co-ordinates based on the equatorial plane, the declination δ and the hour angle t. Using ϕ' as before to denote the latitude of the earth point (50°.1) we have

[2] C. P. Olivier, *Meteors*, 1925 (Williams & Wilkins), p. 167.

[3] R. A. McIntosh, *J.R.A.S.C. vol. 32*, 18 (1938).

[4] Olivier, *op. cit.*, p. 168. Some unfortunate errors have crept into the last few lines of the derivation of this relation.

$$\sin \delta = \sin \phi' \cos \zeta + \cos \phi' \sin \zeta \cos A:$$
$$\cos t = \frac{\cos \zeta - \sin \phi' \sin \delta}{\cos \phi' \cos \delta}.$$

Hence $\delta = +29°.4$, $t = +96°.1 = 6^h24^m.4$ west. At 0040 M.S.T. = 0740 G.C.T. on June 2nd, the right ascension of the mean sun was $4^h40^m.7$ and its Greenwich hour angle 19^h40^m. Hence Greenwich sidereal time was $0^h20^m.7$. Since the earth point is at longitude $7^h02^m.1$ west, the sidereal time there at the moment of the meteor's appearance was $\theta = 17^h18^m.6$. This gives the right ascension of the radiant, $\alpha = \theta - t = 10^h54^m$ or 163°.6. The corrections[5] to these co-ordinates for diurnal aberration, i.e. due to the displacement in direction of the earth point from the centre of the earth, are smaller than the uncertainty transmitted through the computation from very approximate observational data. For the same reason the calculation of an orbit seems unjustified.

Summary of Real Path

Time of apparition 1946, June 1-2, 12:40 a.m., M.S.T. = June 2.319 U.T.
Appeared at height 61 km. over 107°32′W, 49°33′N.
Disappeared at height 24 km. over 106°19′W, 49°53′N.
Earth point 105°32′W, 50°06′N; sidereal time 255°.9.
Length of path (true) 103 km.; (projected) 95 km.
Duration, approx. 3.2 seconds; apparent velocity 32 km./sec.
Slope of path 21°, from azimuth S66°W.
Radiant, corrected for zenith attraction, $\alpha = 164°$, $\delta = +29°$.
True velocity (geocentric) 30 km./sec.; (heliocentric) 42 km./sec.

Department of Mathematics,
University of Saskatchewan,
Saskatoon, July, 1947.

[5] *Ibid.*, p. 169.

THE NEED FOR TRAINING STUDENTS IN CELESTIAL MECHANICS*

By G. M. Clemence

Director Nautical Almanac, U.S. Naval Observatory

EVIDENCE of the need for more widespread teaching of elementary celestial mechanics at the upper undergraduate level may be presented on the basis of two different approaches. (I should remark parenthetically that I speak of the upper undergraduate level because until this period the student is likely not to have had enough mathematics to enable him to tackle the subject; and yet he is not able intelligently to decide whether he wants to do serious graduate work in celestial mechanics unless he has had some knowledge of it as an undergraduate.) First, it may be inquired why any branch of any science should be generally taught at this level, and if any reasons be found we may see whether they apply to celestial mechanics; this may be called the positive approach. Second, on the negative side, we may ask why the subject is not more widely taught; the answer may help us to decide whether the present condition of neglect is a healthy one—whether the main body of astronomy is likely to flourish the better if one of its members is lopped off—or whether a serious attempt ought to be made to revitalize the ailing part. It would be easy to speak at length along these two lines, but for the lack of time I shall be compelled to touch very briefly on only a few of the chief arguments.

Americans are noted for their materialism, and perhaps we may therefore be excused for considering first the materialistic reason for training students in a science at a level one degree above the lowest. That is the demand that exists in industry and government for the services of such persons in applying what they have learned. It is undeniable that some persons are anxious to study a subject that will enable them to earn a comfortable living after graduation. This is one reason for the expansion of the physics and chemistry departments of many of our universities during the past few decades.

It is well known that the applications of celestial mechanics in industry and government are limited, but it may not be appreciated

*Given at the Teachers' Conference of the American Astronomical Society at Evanston, Illinois, 5 September 1947.

that even this limited demand is not being met. At the Naval Observatory there are perhaps twenty persons for whom a course in celestial mechanics might properly be considered a prerequisite for their jobs. Of this number less than half have ever taken such a course. It is impossible to find the requisite number of persons properly trained for carrying on the routine work of time determination, meridian astronomy, and compilation of the *American Ephemeris* and the *Almanacs*. This means that the energy of the senior staff has to be diverted from research to training and instruction, or even to actual performance of routine tasks.

What is not so well known is that a significant demand exists, both in industry and government, for celestial mechanicians with the doctorate. And I have already indicated that students are not likely to do graduate work in this branch unless they already have some knowledge of it. Strangely enough, this demand is not for persons to do research in celestial mechanics, if we leave aside the small amount done at the Naval Observatory, which is likely to increase in the near future. Neither is the demand primarily for applications to rocket navigation, artificial satellites, or interplanetary travel; these matters do not as yet require much manpower. Instead of these, the demand is for experts in the art of computation, and I must say at once that by the art of computation I do not mean the addition and multiplication of numbers. This can be done by machines more efficiently than by persons. By the art of computation I mean the art of formulating a problem so as to make it susceptible of numerical treatment, of doing this in such a way as to make it soluble by machines in the available time, which may be an hour or a year, but not a century; and of ascertaining that the result, when it is obtained, is correct. It may seem strange that celestial mechanicians should have a peculiar facility for this sort of thing; but experience has shown it to be so, both here and abroad; and I can only explain it by the long tradition of computing that celestial mechanicians have behind them and by the exceptionally complete training which the subject provides in formulating and solving a problem on the basis of fundamental *theoretical principles*, by a procedure that is adapted to obtaining a solution *adequate to the purposes in hand*, which is of a form adapted to numerical application with data of the character available, and which must then be put in form for *convenient practical use.*

If time permitted, I might tell some interesting stories about millions of dollars, and even lives, that have been lost because competent computers were not available, and about months of labour that have been expended only to get a result that was wrong, when the correct one might have been obtained in a few hours. But I can merely state that really expert computers can command their own price in any one of a dozen different fields; and that if any celestial mechanician is actually engaged in practicing or teaching the subject it is not because he loves money.

The second reason why celestial mechanics or any other specialized branch of any science should be more widely taught is that by being exposed to the subject some students may learn to love it, and may go on later to make original contributions to this field of knowledge. Even though not followed up, this awakening of interest is worth while to the individual, and indirectly of benefit to the continued welfare of astronomy. I think that most of us here to-day who have made contributions to some branch of astronomy will agree that they have been brought about in this way. Moreover, advances in celestial mechanics have often been the occasion of important advances in mathematics and its application to physics, and it has not yet been applied to all the branches of astronomy that it is capable of.

One reason why celestial mechanics is not more widely taught is that it is often referred to as a difficult subject, and this probably discourages many students. Much has been made of the twenty-five years that E. W. Brown spent on his theory of the moon and of the ten years that Hill devoted to adding and multiplying numbers connected with the motion of Jupiter and Saturn. But difficulty should be distinguished from labour and drudgery. Much of the alleged difficulty of celestial mechanics is only the labour which has now been mitigated by modern computing machines; however, the subject *is* difficult. This difficulty should be a challenge; and, because of the particular phenomena with which the subject is concerned, exceptional satisfaction should be derived from achievements in celestial mechanics.

The impression exists in some quarters that celestial mechanics is a closed book, that nothing remains to be done, and that no new discoveries can be made. Nothing could be further from the truth. It is true that in the numerical applications the work needed may

be in seven or eight significant figures, instead of two or three, as in some other branches, but is this a valid reason for dismissing it? It should be remembered that if astronomers had been satisfied with four significant figures the theory of relativity would never have received observational confirmation, and who can say what wonderful and important discoveries may await us a little further on? I am not aware that the first and second decimal places are more sacred than the eighth, in spite of their being more quickly written down. And it should be emphasized again that celestial mechanicians no longer need to be calculating machines. On the theoretical side also much remains to be done. We do not yet have planetary theories developed that are capable of representing the motions for more than a few centuries. No complete critical examination has been made of the work of Henri Poincaré, although this is a very promising field. Practically nothing is known about the stability of the solar system beyond a few elementary oversimplified theorems which certainly are too restrictive. For the rest I merely state that during the past year I have heard specific pieces of valuable research proposed which in the aggregate, I have no doubt, might occupy fifty persons for fifty years.

I conclude, therefore, that the present seeming lack of interest in celestial mechanics is not due to any innate lack of merit, but merely to a fortuitous combination of circumstances. The growth of other branches of astronomy and the contagious enthusiasm brought about by important fundamental discoveries have naturally reacted adversely to celestial mechanics because of the relatively small total number of astronomers and because of the rapid progress possible in hitherto unopened fields.

It is time that notice should be taken of the danger, and serious effort should be made to abate it. It is, of course, much easier to say this than it is to accomplish it. It is perfectly natural for teachers to prefer to offer courses in the fields in which they themselves are working. Nevertheless, I am sure there are some who are deterred only by the lack of text-books on celestial mechanics. The labour of teaching a course without a suitable text is very great; and it is not clear to me how the lack is to be filled. I will, however, offer three general observations on the writing of text-books, which like nearly all general observations, may have some exceptions. First, the best books are written by teachers. Second, a teacher

generally writes a better book after he has taught a course for several years rather than before. Third, the most eminent original thinkers are not necessarily the best authors.

Along with more widespread teaching of celestial mechanics greater attention should be directed to fundamental astronomy in general. The two are interdependent; and, in turn, the rest of astronomy is dependent upon them.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Ben-Hur: The Star of Bethlehem

From the announcements of publishers it is evident that there is a revival of interest in the works of fiction produced seventy-five to a hundred years ago—in the Victorian period—and the present writer was pleased to read in *The Times Literary Supplement* the statement that the poet Tennyson is steadily growing in favour again. A famous narrative of those days was "Ben-Hur" by Lew Wallace (1827-1905), lawyer, diplomat and noted leader of the northern forces in the American Civil War. It is an absorbing tale of the coming of Christ and appeared in 1880. A few years later the present writer obtained a copy of the book and on February 21, 1889, being on the programme of the College Y.M.C.A. weekly meeting to speak on the subject "Seeking Christ," he tried to obtain some ideas from Wallace's account of the visit of the Magi to Bethlehem. About 1893, there was a course in Toronto featuring American writers, and in it Wallace gave an admirable lecture on his well-known work. Those were the days of the flaunting of agnosticism and the testing of religious beliefs in the fires of controversy. In closing his address, Wallace stated that when he undertook the writing of his book he had many doubts regarding the truth of some parts of the Scriptures but that when the work was completed he was a firm believer.

The present writer's copy of "Ben-Hur" disappeared many years ago but within the last twelve months a copy of an early edition was picked up on a bargain counter for a dime. The astronomer, as well as the ordinary reader, is interested in the author's description of the Star of Bethlehem. He pictures the people sleeping on the roof of the khan (the *inn* of Luke 2.7):

> About midnight someone on the roof cried out, "What light is that in the sky? Awake, brethren, awake and see!"
>
> . . . . . .
>
> And this was what they saw. A ray of light, beginning at a height immeasurably beyond the nearest stars, and dropping obliquely to the earth; at its top a diminishing point; at its base, many furlongs in width; its sides blending softly with the darkness of the night; its core a roseate electrical splendour. The ap-

parition seemed to rest on the nearest mountain southeast of the town, making a pale corona along the line of the summit. The khan was touched luminously, so that those upon the roof saw each other's faces, all filled with wonder.

Steadily, through minutes, the ray lingered, and then the wonder changed to awe and fear; the timid trembled; the boldest spoke in whispers.

"Saw you ever the like?" asked one.

"It seemed just over the mountain there. I cannot tell what it is, nor did I ever see anything like it," was the answer.

"Can it be that a star has burst and fallen?" asked another, his tongue faltering.

"When a star falls, its light goes out."

"I have it!" cried one, confidently. "The shepherds have seen a lion, and made fires to keep him from the flocks."

The men next the speaker drew a breath of relief, and said, "Yes, that is it! The flocks are grazing in the valley over there to-day."

A bystander dispelled the comfort.

"No, no! Though all the wood in all the valleys of Judah was brought together in one pile and fired, the blaze would not throw a light so strong and high."

After that there was silence on the house-top, broken but once again while the mystery continued.

The mystery will always continue! Not enough definite information is provided to enable one to give a satisfactory physical explanation of the phenomenon.

Then there are the names of the horses in the famous chariot race and of their parents:

"Mira—Sirius—names of stars, are they not, O sheik?" asked Ben-Hur, going to each of the four, and to the sire, offering his hand.

"And why not?" replied Ilderim. "Wert thou ever abroad on the desert at night?"

"No."

"Then thou canst not know how much we Arabs depend upon the stars. We borrow their names in gratitude, and give them in love. My fathers all had their Miras, as I have mine; and these children are stars no less. There, see thou, is Rigel, and there Antares; that one is Atair, and he whom thou goest to now is Aldebaran, the youngest of the brood, but none the worse of that—no, not he!"

C. A. C.

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For many years the Toronto organization existed alone, but now the Society is national in extent, having active Centres in Montreal and Quebec, P.Q.; Ottawa, Toronto, Hamilton, London and Windsor, Ontario; Winnipeg, Man.; Edmonton, Alta.; Vancouver and Victoria, B.C. As well as nearly 1,200 members of these Canadian Centres, there are over 400 members not attached to any Centre, mostly resident in other nations, while some 50 additional institutions or persons subscribe to our publications.

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